5.11 Noise

This chapter describes vehicle noise costs, including general information on how noise is quantified, the noise emissions of various types of vehicles, and estimates of noise cost values.

5.11.1 Chapter Index

5.11.2 Definition

Noise refers to unwanted sounds and vibrations. Motor vehicles cause various types of noise, includes engine acceleration, tire/road contact, braking, horns and vehicle theft alarms. Heavy vehicles can cause vibration and infrasound (low frequency noise). According to an OECD report, "*Transport is by far the major source of noise, ahead of building or industry, with road traffic the chief offender.*"[1] Motorcycles, trucks and buses are major contributors to traffic noise.[2] At low speeds most noise comes from vehicle engine and drivetrain, at higher speeds aerodynamic and tire/road noise dominate.[3]

[1] OECD (1990), *Environmental Policies for Cities in the 1990s*, OECD (www.oecd.org), cited in Poldy, p.29.
[2] MacKenzie, Dower & Chen (1992), *The Going Rate*, World Resources Institute (www.wri.org), p. 21.
[3] Homberger, Kell and Perkins (1992), *Fundamentals of Traffic Engineering, 13th Edition*, Institute of Transportation Studies, UCB (www.its.berkeley.edu), p.31-3.

5.11.3 Discussion
Several factors affect the amount of noise emitted by traffic, and its costs:

- *Vehicle type*. Motorcycles, heavy vehicles (trucks and buses), and vehicles with faulty exhaust systems tend to produce high noise levels.
- *Engine type*. Older diesel engines tend to be the noisiest, followed by gasoline and natural gas, hybrid, and electric vehicles being quietest.
- *Traffic speed, stops and inclines*. Lower speeds tend to produce less engine, wind and road noise. Engine noise is greatest when a vehicle is accelerating or climbing an incline. Aggressive driving, with faster acceleration and harder stopping, increases noise.
- *Pavement type and condition*. Certain pavement types and smoother road surfaces emit less noise.[4] "Quiet pavement" research indicates that *open-graded friction course* (OGFC) and *porous friction courses* (PFC) asphalts, and *whisper grinding* and *longitudinal tining* produce less traffic noise.[5]
- *Distance and barriers*. Noise declines with distance and is reduced by structures, walls, trees, hills and sound-resistant design features such as double-paned windows.

Noise is measured using hedonic price surveys, as discussed in Chapter 4.[6] This involves the effects of noise on residential property values. Several studies show residential property values typically decline about 0.5% for each unit change in Leq.[7] These results are used to develop general property value depreciation indexes.[8] The OECD recommends a noise depreciation index of 0.5% of property value per decibel increase if noise levels are above 50 dB(A) Leq (24 hours).[9] Lee estimates traffic noise costs at $21 annually per housing unit per decibel increase.[10]

Such studies are criticized on several grounds. Their noise level thresholds tend to be arbitrary, the data used are often incomplete, they assume that home buyers have accurate knowledge of noise exposure at each location, and they do not account for non-residential noise impacts (such as on businesses and pedestrians). Most U.S. noise cost models measure the marginal cost of an additional highway vehicle, and so are inappropriate for

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[4] Bill Wilson (2005), "New Noise Solution Research Shows Promise And An Enthusiastic Effort," *Roads & Bridges*, Vol. 43 No. 2 (www.roadsbridges.com), February 2005.
[5] FHWA (2005), *Quiet Pavement Pilot Program*. FHWA (www.fhwa.dot.gov); at www.fhwa.dot.gov/environment/noise/qpppeml.htm
[6] EC (2005), *ExternE: Externalities of Energy - Methodology 2005 Update*, Directorate-General for Research Sustainable Energy Systems, European Commission (www.externe.info).
[7] From Pearce and Markandya (1989), *Environmental Policy Benefits: Monetary Valuation*, OECD (www.oecd.org).
[8] Based on Weatherall 1988; Quinet 1990; and Steeting 1990 as cited in BTCE & EPA (1994), "The Costing and Costs of Transport Externalities: A Review," *Victorian Transport Externalities Study*, Vol. 1, Environment Protection Authority (www.epa.vic.gov.au).
[9] M. Modra (1984), *Cost-Benefit Analysis of the Application of Traffic Noise Insulation Measures to Existing Houses*, EPA (www.epa.vic.gov.au), 1984, cited in Poldy, 1993.
[10] Douglass Lee, "Efficient Highway User Charges," USDOT, as cited in MacKenzie, Dower & Chen (1992), *The Going Rate*, World Resources Institute (www.wri.org).

evaluating surface street traffic noise costs. Verhoef concludes that such estimates of traffic noise represent only 1/8th of the total cost[11] and Bein interprets Sælensminde's research to imply that hedonic noise surveys identify only about 1/6th of total motor vehicle noise costs.[12]

Measuring Noise[13]
Noise is measured in *decibels* (dB), a logarithmic scale. A 10 dB increase represents a doubling in noise level. *Decibels A-weighted*, (indicated "dB(A)") units emphasize the frequency sensitivities of human hearing, and correlate well with subjective impressions of loudness. Common noise levels range from 30 to 90 dB(A). Decibels are an instantaneous measurement, so various indexes are used to measure noise over a period of time:

- *Leq* represents the equivalent continuous sound level in dB(A) for a specific time period. Leq (8 hours) is used in many traffic noise standards established by OECD and WHO.
- *L_{10}* represents the dB(A) level that is exceeded 10% of a time period (often one hour). Analogous measurements, L_{01} L_{05}, L_{50}, refer to noise levels exceeded 1%, 5% and 50% of the time period. L_{10}*(18 hours)* is the mean of the hourly values taken over an 18-hour period, typically from 6 a.m. to midnight. L_{10} is often used to define traffic noise.
- *MNL (Maximum Noise Level)* is the loudest noise during a certain period. Some researches consider this index to correlate with noise annoyance better than Leq and L_{10}, but does not address the number of noise events, and is not widely used.

Decibels Examples

130 - Threshold of pain

120 - Loud car horn close by

110 - Busy airport

100 - Inside underground train

90 - Inside diesel bus

80 - Busy residential road

70 - Conversational speech

60 - Background music

50 - Quiet office

40 - Quiet bedroom

20 - Silent room

10 - Threshold of hearing

One study found that traffic volume increases of a few hundred motor vehicles per day reduced adjacent residential property values by 5-25%.[14] Assuming 150 residences per mile of urban residential street, with average values of $100,000 per residence, this represents an annualized cost of approximately $1 million (5% discount rate over 25 years). Assuming 500 additional vehicles per day cause average property values to decline by 10%, and that noise represents one-third of this cost (reduced safety and privacy are other possible costs), such traffic noise costs average 18¢ per vehicle mile.[15]

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[11] Erik Verhoef (1994), "External Effects and Social Costs of Road Transport," *Trans. Res.*, Vo.28A, p. 286.
[12] Peter Bein (1994), *Barnet Hastings Benefit Cost Analysis*, BC Ministry of Transportation (www.th.gov.bc.ca).
[13] BTCE & EPA (1994), "The Costing and Costs of Transport Externalities: A Review," *Victorian Transport Externalities Study*, Vol. 1, Environment Protection Authority - Victoria, Australia (www.epa.vic.gov.au).
[14] Gordon Bagby (1980), "Effects of Traffic Flow on Residential Property Values," *Journal of the American Planning Association*,(www.planning.org/japa) Vol. 46, No. 1, January, pp. 88-94. Also see William Hughes and C.F. Sirmans (1992), "Traffic Externalities and Single-Family House Prices," *Journal of Regional Science* (www.blackwellpublishing.com), Vol. 32, No. 4, 1992, pp. 487-500.
[15] $2.8 million x 10% ÷ 3 ÷ 365 days per year ÷ 500 vehicles per day.

The number of residences impacted by traffic noise is significant in most developed countries. A.L. Brown and K.C. Lam estimate that approximately 25% of Australian urban dwellings are located on roads with over 2,000 vehicles per day and higher traffic speeds. Over 12% of dwellings in Australia directly front roadways carrying 8,000 or more vehicles per day. In addition, 8% of houses on low volume (<1,000 vehicles per day) are located close enough to a high traffic road to experience traffic noise exceeding 68 dB. Thus, approximately 1/3 of houses experience significant traffic noise.[16]

Table 5.11.3-1 shows estimates of total national transportation noise costs as a percentage of GDP. Some research indicates that property value depreciation due to noise is non-linear, and increases from 0.5% per dB(A) unit increase in the range of 50 to 60 dB(A), rising to 0.8% per unit increase above 65 dB(A).[17]

Table 5.11.3-1 **Selected Estimates of Total Transport Noise Costs**[18]

Country	Percent of GDP
France	0.24
Germany	0.20
Norway	0.23
United Kingdom	0.50
United States,	0.06 - 0.21
Japan	0.20
OECD, Average	0.15

[16] A. L. Brown and K.C. Lam (1994), "Can I Play on the Road, Mum? - Traffic and Homes in Urban Australia," *Road and Transport Research* (www.arrb.com.au), Vol. 3, No. 1, March 1994, p. 12-23.
[17] BTCE & EPA (1994), "The Costing and Costs of Transport Externalities: A Review," *Victorian Transport Externalities Study*, EPA (www.epa.vic.gov.au), Table 3.4, based on Weatherall, 1988.
[18] BTCE & EPA (1994), based on Bouladon 1991 and Quinet 1990.

5.11.4 Estimates

All values are in U.S. dollars unless otherwise indicated.

Summary Table

***Table 5.11.4-1* Noise Studies Summary Table – Selected Urban Values**

Publication	Costs		Cost Value	2007 USD / VMT
FHWA (1997)	Automobile		median values 0.11	0.001
Urban highways	Pickup & Van		0.10	0.001
	Buses		1.72	0.022
1997 cents per	Combination Trucks		3.73	0.048
Vehicle-mile	All Vehicles		0.24	0.003
CE Delft (2008)	Car	Day	0.76	0.014
Urban roads		Night	1.39	0.025
	Motorcycle	Day	1.53	0.027
2000 Euro cents		Night	2.78	0.050
per veh km.	Bus	Day	3.81	0.068
		Night	6.95	0.124
	Heavy truck	Day	7.01	0.125
		Night	12.78	0.228
Delucchi and Hsu	Cars (Urban Arterial)		1.18	0.002
(1998)	Medium trucks		7.02	0.011
	Heavy trucks		20.07	0.031
1991 USD/1000 VMT	Buses		7.18	0.011
	Motorcycle		8.71	0.013
GVRD (1993)	Vehicles		1993* Can. cents/km. 0.5	0.009

*More detailed descriptions of these studies are found below, along with summaries of other studies. 2007 Values have been adjusted for inflation by Consumer Price Index. * Indicates that currency date is assumed to be the same as study date.*

Distance-based Estimates

- Apogee Research estimated noise costs in Boston, MA and Portland, ME for several modes at high, medium and low densities. Totals are shown in Table 5.11.4-2.

Table 5.11.4-2 **Noise Costs in Two Cities (Cents Per Passenger Mile)**[19]

	Automobile		Comm. Rail		Rail Transit		Bus	
Boston	Expwy	Non-Expwy	Peak	Off-P	Peak	Off-P	Peak	Off-P
High	0.3	0.6	0.4	1.1	n/a	n/a	0.5	1.3
Medium	0.1	0.2	0.1	0.3	0.3	0.4	0.2	0.5
Low	<0.1	<0.1	0.1	0.1	n/a	n/a	<1.0	0.1
Portland								
High	0.2	0.5	n/a	n/a	n/a	n/a	1.1	1.0
Medium	0.1	0.1	n/a	n/a	n/a	n/a	0.2	0.2
Low	<0.1	<0.1	n/a	n/a	n/a	n/a	0.1	0.1

- CE Delft (2008) provides a matrix of European cost estimates divided into day and night values, as well as into urban, suburban and rural categories, summarized in Table 511.4-3. The original source includes ranges of values.

Table 5.11.4-3 **Central Road and Rail Traffic Noise Marginal Costs (€ct/vkm)**[20]

Mode	Time	Urban	Suburban	Rural
Car	Day	0.76	0.12	0.01
	Night	1.39	0.22	0.03
Motorcycle	Day	1.53	0.24	0.03
	Night	2.78	0.44	0.05
Bus	Day	3.81	0.59	0.07
	Night	6.95	1.10	0.13
LGV	Day	3.81	0.59	0.07
	Night	6.95	1.10	0.13
HGV	Day	7.01	1.10	0.13
	Night	12.78	2.00	0.23
Passenger Train	Day	23.65	20.61	2.57
	Night	77.99	34.40	4.29
Freight Train	Day	41.93	40.06	5.00

- Austroads estimates that urban traffic noise costs aveage $1.81 for cars, $1.67 for buses and $1.55 for train travel per 1,000 passenger-kilometers.[21]

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[19] Apogee Research (1994), *The Costs of Transportation*, Conservation Law Foundation (www.clf.org), p. 161.
[20] M. Maibach, et al. (2008), *Handbook on Estimation of External Cost in the Transport Sector,* CE Delft (www.ce.nl) Table 22 p 69; at http://ec.europa.eu/transport/costs/handbook/doc/2008_01_15_handbook_external_cost_en.pdf
[21] Caroline Evans, et al. (2015), *Updating Environmental Externalities Unit Values*, Austroads (www.austroads.com.au); at www.onlinepublications.austroads.com.au/items/AP-T285-14.

- Delucchi and Shi-Ling Hsu calculate marginal noise costs per 1,000 miles traveled for five vehicle classes on six urban roadway types, as indicated in the table below. Their model takes into account the impacts of traffic noise above a threshold on residential property values, scaled up 27% to include non-residential exposures.[22]

Table 5.11.4-4 Marginal Noise Costs in Urban Areas (1991$/1000 VMT)[23]

	Interstate	Other Freeways	Principle Arterials	Minor Arterials	Collectors	Local Roads
Light Automobiles	2.96	4.25	1.18	0.57	0.07	0.00
Medium Trucks	8.50	13.20	7.02	5.37	1.05	0.00
Heavy Trucks	16.69	30.80	20.07	29.93	4.93	0.00
Buses	6.36	9.77	7.18	6.42	1.22	0.00
Motorcycles	17.15	27.03	8.71	4.67	0.56	0.00

- Table 5.11.4-5 summarizes marginal highway noise costs for various vehicles estimated by the US Federal Highway Administration. This reflects the marginal cost of an additional vehicle on major highways, and does not reflect noise exposure on surface streets, where the vehicle noise impact costs are likely to be higher.

Table 5.11.4-5 Estimated Highway Noise Costs (1997 Cents Per Vehicle Mile)[24]

	Rural Highways			Urban Highways			All Highways		
	High	Med.	Low	High	Med.	Low	High	Med.	Low
Automobile	0.03	0.01	0.00	0.30	0.11	0.03	0.20	0.06	0.02
Pickup & Van	0.03	0.01	0.00	0.27	0.10	0.03	0.17	0.06	0.02
Buses	0.35	0.13	0.04	4.55	1.72	0.48	2.79	1.06	0.30
Single Unit Trucks	0.27	0.10	0.03	3.14	1.19	0.33	1.85	0.70	0.20
Combination Trucks	0.68	0.26	0.07	9.86	3.73	1.05	4.24	1.61	0.45
All Vehicles	0.08	0.03	0.01	0.64	0.24	0.07	0.42	0.16	0.05

[22] Their conclusion that vehicles produce minimal noise costs on collectors and no noise costs on local roads is contradicted by other studies which indicate that residential property values along low volume roads are quite sensitive to changes in traffic volume, such as Gordon Bagby (1980), "Effects of Traffic Flow on Residential Property Values," *Journal of the American Planning Association* (www.planning.org/japa), Vol. 46, No. 1, pp. 88-94). This suggests that their "Base-Case" estimates are probably low.

[23] Mark Delucchi and Shi-Ling Hsu (1998), "External Damage Cost of Noise Emitted from Motor Vehicles," *Journal of Transportation and Statistics* (www.bts.gov/publications/jts),Vol. 1, No. 3, pp. 1-24. Also see Mark Delucchi (2000), "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, (www.bath.ac.uk/e-journals/jtep),Vol. 34, No., pp. 135-168.

[24] FHWA (1997) *1997 Federal Highway Cost Allocation Study*, USDOT (www.dot.gov), Table V-22; at www.fhwa.dot.gov/policy/hcas/summary/index.htm.

- Forkenbrock estimates noise pollution costs for large intercity trucks to average 0.04¢ per ton-mile of freight shipped.[25]

- Table 5.11.4-6 shows estimated residential noise damage costs for travel on high-volume highways. Separate cost estimates are also provided for various weight trucks. They state that "*As traffic volume on a particular road increases, the [marginal] noise damage contribution of a single vehicle decreases*" which implies higher marginal costs for vehicle travel on low volume, local roads and streets.

Table 5.11.4-6 **Costs Per Noise Passenger Car Equivalent (1993 Cents Per Mile)[26]**

Miles Per Hour:	20	25	30	35	40	45	50	55	60
Urban, CBD	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.24
Urban Fringe	0.02	0.03	0.08	0.13	0.19	0.25	0.32	0.40	0.51
Urban, Outer CBD	0.00	0.01	0.02	0.03	0.05	0.06	0.08	0.10	0.12
Urban, Residential	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.19	0.23
Urban, Rural Character	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Rural, Sparse Development	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rural, Dense Development	0.02	0.03	0.06	0.08	0.12	0.16	0.20	0.24	0.28

This table indicates estimated residential noise costs for motor vehicle travel on 110,000 average annual daily traffic highways.

- Per Kågeson estimates motor vehicle noise costs in Europe at 0.6¢ per passenger mile (3.0 ECU/1,000 km).[27]

- Theodore Keeler et al. estimated the marginal noise cost of an added freeway vehicle mile at 0.1-0.2¢ in 1975 (0.2-0.4¢ in current dollars), but offer no estimate for impacts on local streets, which they state would be considerably higher.[28]

- David Maddison, et al, develop an estimate of noise costs for the U.K. as summarized in Table 5.11.4-7. They assume that heavy trucks produce 3 times, and buses and motorcycles twice, the noise costs of an average automobile.[29]

Table 5.11.4-7 **Noise Costs Per Kilometer**

	Pence Per Passenger Km	1996 US$ Per Passenger Mile
Car	0.41	$0.018
Bus	0.097	$0.004

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[25] David Forkenbrock 1999, "External Costs of Intercity Truck Freight Transportation," *Transportation Research A* (www.elsevier.com/locate/tra), Vol. 33, No. 7/8, Sept./Nov. 1999, pp. 505-526.

[26] Daniel Haling and Harry Cohen (1997), "Residential Noise Damage Costs Caused by Motor Vehicles," *Transportation Research Record 1559*, (www.trb.org), 1997, pp. 84-93.

[27] Per Kågeson (1993), *Getting the Prices Right*, European Fed. for Transport & Env. (www.transportenvironment.org), p 102.

[28] IURD (1975), *The Full Cost of Urban Transportation*, Monograph 21, Institute of Urban and Regional Development (http://iurd.berkeley.edu), p. 52.

[29] David Maddison, et al (1996), *The True Costs of Road Transport*, Earthscan (www.earthscan.co.uk), p. 95.

Motorcycle	1.18	$0.035
Heavy Goods Vehicle	1.96	$0.053

- Peter Miller and John Moffet estimate noise costs at 0.14¢ to 0.23¢ per automobile mile and three times higher for buses.[30]

- Quinet summarizes noise cost estimates by various European researchers, indicating an average estimate of approximately 0.7¢ per vehicle mile (U.S. dollars).[31]

- In an example assuming $1,000 per linear meter of highway noise barrier L.R. Rilett calculates that mitigation costs average about 3¢ per peak period vehicle kilometer, or about 1¢ for automobiles, 14¢ for medium trucks, and 43¢ for heavy trucks.[32]

- Sælensminde uses previous studies to estimate noise costs for Norway, resulting in a range from $88 to $541 per capita annually, or about 1¢ to 5.4¢ per VMT.[33]

- Transport 2021 estimates noise costs in the Greater Vancouver area equals 0.5¢ Canadian per km, or about 0.6¢ U.S. per mile.[34]

Other Estimates and Studies

- Bagby compared property values in two similar residential neighborhoods, one of which had unrestricted traffic flow, while the other had various traffic management strategies that significantly reduced traffic volumes. The results show that residential property values are highly sensitive to traffic on adjacent streets. Reducing traffic volumes by a few hundred motor vehicles per day increased adjacent residential property values by 5-25%.[35] Other studies found similar results.[36]

- An comprehensive study by Bateman, et al, indicates that that each decibel increase in traffic noise decreases residential property price in Scotland by 0.20%, with a standard error indicating that there is a 95% chance that the coefficient is greater than

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[30] NRDC (1993), *The Price of Mobility*, National Resources Defense Council (www.nrdc.org), Oct. 1993, p.35.
[31] Emile Quinet (1997), "Full Social Cost of Transportation in Europe," *The Full Costs and Benefits of Transportation*, Springer (www.springer.com), pp. 69-111, Table A1.
[32] L.R. Rilett (1995), "Allocating Pollution Costs Using Noise Equivalency Factors," *Transportation Research Record 1498*, TRB (www.trb.org), pp. 102-107.
[33] Kjartan Sælensminde (1992), *Environmental Costs Caused by Road Traffic In Urban Areas - Results From Previous Studies*, Institute for Transport Economics (www.toi.no).
[34] GVRD (1993), *Cost of Transporting People in the BC Lower Mainland*, GVRD (www.metrovancouver.org).
[35] Gordon Bagby (1980), "Effects of Traffic Flow on Residential Property Values," *Journal of the American Planning Association*, Vol. 46, No. 1, APA (www.planning.org), January 1980, pp. 88-94.
[36] William Hughes and C.F. Sirmans (1992), "Traffic Externalities and Single-Family House Prices," *Journal of Regional Science*, Vol. 32, No. 4, (www.blackwellpublishing.com/), pp. 487-500.

-0.04% and less than -0.37%.[37] The study also indicates that aircraft noise has a similar effect, and that views of roads also reduces residential property values.

- Research by the B.C. Ministry of Transportation and Highways indicates that noise costs average $1,000-1,500 (Canadian dollars) or more per affected person per year (residents of homes near busy streets and highways).[38]

- Hokanson developed the relative noise factors shown in Table 5.11.4-8

Table 5.11.4-8 **Automobile Noise Equivalents by Speed**[39]

MPH:	20	25	30	35	40	45	50	55	60
Automobile	1	1	1	1	1	1	1	1	1
Medium Truck	18	16	15	14	13	13	12	12	11
Heavy Truck	113	83	66	54	45	38	32	30	26

- The Dutch Ministry of Environment publishes extensive research on transportation noise impacts, including formula and software for calculating impacts in specific conditions.[40] Their findings indicate that residents are more annoyed by aircraft and highway traffic than the same noise level produced by local traffic and railroads.[41]

- A Federal Transit Administration study indicates that as "Day-Night" sound level increases from 50 to 90 Ldn, the portion of residents who are highly annoyed by noise increases from approximately 0 to 100%.[42] This study indicates that at 50 feet, a 2-car LRT (Light Rail Transit) traveling at 25 mph produces about 52 dBA, a 4-car LRT at 25 mph produces about 60 dBA, and a RRT (Rapid Rail Transit) at 50 mph produces about 66 dBA (the equivalent noise of a heavy arterial traffic at 40 mph).

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[37] Ian Bateman, Brett Day, Iain Lake and Andrew Lovett (2001), *The Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study*, Scottish Executive Development Department (www.scotland.gov.uk); at www.scotland.gov.uk/library3/housing/ertpv.pdf

[38] Dr. Peter Bein (1997), *Monetization of Environmental Impacts of Roads*, Planning Services Branch, B.C. Ministry of Transportation and Highways (www.gov.bc.ca/tran).

[39] Barry Hokanson and Martin Minkoff (1981), *Measures of Noise Damage Costs Attributable to Motor Vehicle Travel - Technical Report #135*, Urban and Regional Research, University of Iowa (www.uiowa.edu).

[40] VROM (1995), *Calculation of Road Traffic Noise*, Directorate for Noise and Traffic (www.vrom.nl); at www.xs4all.nl/~rigolett/ENGELS/index.html

[41] VROM (1993), *Response Functions for Environmental Noise in Residential Areas*, Ministry of Environment (www.vrom.nl).

[42] Harris Miller & Hanson, Inc. (1995), *Transit Noise and Vibration Impact Assessment*, Federal Transit Administration (www.fta.dot.gov), DOT-T-95-16, April 1995.

- Based on an review of available research, Gillen estimates that aviation noise reduces housing prices by 0.9% for each Noise Explores Factor (NEF) decibel increase.[43]

- A study of car alarm noise in New York City found that 91% of surveyed respondents said that car alarms reduced their quality of life, 76% said car alarms wake them at night, only 5% have responded to the sound of an alarm by calling the police about a possible theft, while 60% have called police to complain about car alarm noise.[44] It also found that car alarms are not very effective at preventing thefts: 95-99% of all alarms are false and cars with alarms are just as likely to be broken into those without.

- Swedish researcher Ulf Sandberg finds that tire/road noise is a major portion of total traffic noise.[45] He responds to the following "myths" concerning tire/road noise:
    - *Tyre/road noise has become a concern only during the last decades, say from the 1970s.* It is shown that tyre/road noise was already an important issue long ago.
    - *Tyre/road noise is an important part of vehicle noise at speeds above 50 km/h (70 for trucks).* The truth is that nowadays tyre/road noise dominates during almost all types of driving for cars and down to about 40 km/h for trucks (vehicles meeting EU requirements).
    - *Manufacturers have done a lot to reduce vehicle and tyre/road noise.* Yes, in some respects; however, it seems that vehicle noise has in some cases increased rather than decreased.
    - *Speed has great influence but it does not attract much very interest.* It is shown that there are unexpected relations between speed-related factors and that these can be useful in data presentation.
    - *Different road surfaces may give a large variation in noise levels.* True, the variation is very large, but the most common and useful surfaces are close together on the noise scale.
    - *Tyres do not differ very much in noise emission.* This is not true, the variation is large if a sufficient number of tyre types is included in the data set.
    - *Winter tyres are much more noisy than summer tyres.* This is a myth based on the past. Currently, winter tyres may be the "quiet" tyres.
    - *The width of the tyre is a very influential factor.* Essentially true: A noise-width relation covering the range from "tiny" bicycle tyres to large truck tyres is presented.
    - *Tyre/road noise from a heavy truck is far above that from a typical car.* Not true, one may find heavy trucks that emit lower tyre/road noise than some cars.
    - *Tyre/road noise is very broadband nowadays.* True and not true - current tyres emit noise very much concentrated within the 1 kHz octave. Tone correction may be considered.
    - *Quiet tyres are possible only if safety is sacrificed.* Recent results show that there is no tradeoff between low noise emission and high safety.
    - *We cannot afford to reduce tyre/road noise.* Calculation exercises are presented that suggest that low-noise tyres as well as low-noise road surfaces may be very cost effective.

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43 David Gillen (2003), "The Economics of Noise," *Handbook of Transport and the Environment*, Elsevier (www.elsevier.com), pp. 81-95.

44 TA (2003), *Alarmingly Useless: The Case for Banning Car Alarms in NYC*, Transportation Alternatives (www.tstc.org) and BanCarAlarms.Com (www.transalt.org/campaigns/caralarms).

45 Ulf Sandberg (2001), *Tyre/Road Noise – Myths and Realities*, Swedish National Road And Transport Research Institute (www.vti.se).

- o *Tyre/road noise will be substantially reduced by the introduction of European Union noise emission limits.* Not true; the new tyre noise emission limits will be almost totally ineffective.

- A Swiss government study estimated that road traffic noise costs totaled 869 million Swiss Francs (CHFs) in 2000, of which 63% or 550 million CHF are caused by passenger transport, and 37% or 320 million CHF are caused by freight transport. The corresponding figure for rail traffic is 129 million CHF (79% passenger and 21% freight transport). Aggregate road and rail-related noise costs totaled 998 million CHF. This figure corresponds to 140 CHF per capita, or 0.25%.[46]

- The STAMINA model calculates relative noise costs of trucks and automobiles.[47]

- van Essen, et al describe various methods for calculating traffic noise costs.[48] They recommend the Impact Pathway Model, which involves these five steps:
    1. Estimate the emission from the source of noise.
    2. Determine the type of impact to human health, agriculture, natural environment, material damage etc).
    3. Estimate the number of persons, animals, plants exposed to various ambient noise levels over time.
    4. Establish the relationship between noise exposure and the various health and welfare effects; and predict ultimate noise impacts basd on these relationships.
    5. Calculate the monetary value of effect on health and other. An appropriate method would be market prices if market exists, and otherwise the willingness to pay to avoid or to accept small changes in risks if no market price is available.

- The Washington State Department of Transportation spends a maximum of $5,500 to $20,000 per exposed household to reduce highway traffic noise levels.[49] This effectively places a price on traffic noise.

- A U.K. study found significant concern about traffic vibration.[50] Along roads with 500 or more vehicles per hour during peak periods, over 50% of residents are

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[46] Swiss ARE (2004), *External Noise Costs of Road and Rail Traffic in Switzerland in 2000 (Externe Lärmkosten des Strassenund Schienenverkehrs der Schweiz, Aktualisierung für das Jahr 2000)*, Swiss Federal Office of Spatial Development (www.are.admin.ch); at www.are.admin.ch/themen/verkehr/00252/00472/03389/index.html?lang=en.
[47] Wisconsin Department of Transportation (1988), *Facilities Development Manual: Ch. 23, Section 25, Subject 10* (www.dot.state.wi.us); at https://trust.dot.state.wi.us/static/standards/fdm/23/23-25-10.pdf
[48] van Essen, et al (2004), *Marginal Costs of Infrastructure Use – Towards a Simplified Approach*, CE Delft; published in Vermeulen, et al (2004), *The Price of Transport*, CE Delft (www.ce.nl).
[49] WSDOT (1987), Directive 22-22 *Noise Evaluation Procedures for Existing State Highways*, Washington State DOT (www.wsdot.wa.gov).
[50] G.R. Watts (1990), *Traffic Induced Vibrations in Buildings*, TRRL Report #246, (www.trl.co.uk).

bothered by traffic vibration. However, field studies and case studies showed only minimal and superficial structural damage caused by motor vehicle vibration

- The World Health Organization estimates that in the Western European countries, environmental noise causes a total loss of 1.0–1.6 million disability-adjusted years of life (DAYL), including 61,000 from increased ischaemic heart disease, 45,000 years for cognitive impairment of children, 903,000 years for sleep disturbance, 22,000 years for tinnitus, and 587,000 years for annoyance.[51] Sleep disturbance and annoyance related to road traffic noise constitute most of the burden.

5.11.5 Variability

Noise impacts vary by vehicle type and condition, location and time. Automobiles are generally quieter than buses and motorcycles. Electric and electric /ICE hybrid vehicles generally produce low motor noise at low speeds, and wheel noise (the primary source of noise at higher speeds) comparable to gasoline and diesel vehicles. Noise costs are higher in urban areas, where there are more human ears, but an additional vehicle in quite rural areas imposes greater marginal cost than in urban traffic. Noise also impacts wildlife and so imposes environmental as well as human impacts.

5.11.6 Equity and Efficiency Issues

Noise is an external cost, and therefore inequitable and inefficient. It tends to be a particularly significant cost for urban residents, people living near highways, pedestrians and cyclists. Disadvantaged populations tend to be particularly exposed to this impact.

5.11.7 Conclusions

Noise is one of the most obvious and often-mentioned negative impacts of motor vehicle traffic. Traffic noise can discourage outdoor activities and make some locations undesirable for housing or other land uses that require quiet. People often justify moving or visiting rural areas by explaining that they enjoy the "peace and quiet." Motor vehicles, and sometimes air traffic, are dominant sources of noise in many areas.

Several studies monetize traffic noise costs. Many of these were designed to identify the marginal cost of additional vehicles on major highways and so are not sensitive to urban street traffic noise, where a few additional daily vehicle trips can significantly affect ambient noise and property values. Such studies often fail to account for non-residential impacts, and incorporate arbitrary thresholds of traffic volumes and distance between homes and streets at which noise is considered a "problem." For these reasons, such studies appear to undervalue urban traffic noise costs.

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[51] WHO (2010), *Burden of Disease from Environmental Noise: Quantification of Healthy Life Years Lost in Europe*, The World Health Organization (www.euro.who.int); at www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf.

Most studies place average automobile noise costs at 0.1¢ to 2¢ per vehicle mile, but actual noise costs are probably much higher. Automobile noise costs are estimated here at 1.3¢ per mile on urban roads and rural 0.7¢ on rural roads, based on existing cost estimates increased to take into account non-residential and residual costs. Electric cars are estimated to produce 30% of the noise cost of an automobile under urban conditions, and 60% during higher speed rural driving. Diesel bus noise is estimated to be 5 times greater than an automobile. Electric bus and trolley noise are estimated to be 3 times greater than an automobile, and motorcycles are estimated to be 10 times greater than an automobile. Rideshare passengers, bicycling, walking and telecommuting impose no noise costs.

Table 5.11.7-1 **Estimate - Noise Costs (2007 U.S. Dollars per Vehicle Mile)**

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.013	0.013	0.007	0.011
Compact Car	0.013	0.013	0.007	0.011
Electric Car	0.004	0.004	0.004	0.004
Van/Light Truck	0.013	0.013	0.007	0.011
Rideshare Passenger	0.000	0.000	0.000	0.000
Diesel Bus	0.066	0.066	0.033	0.053
Electric Bus/Trolley	0.040	0.040	0.020	0.032
Motorcycle	0.132	0.132	0.066	0.106
Bicycle	0.000	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Telecommute	0.000	0.000	0.000	0.000

Automobile Cost Range

These are based on estimates cited above.

Minimum	Maximum
$0.003	$0.08

5.11.8 Information Resources

Resources listed below provide information on traffic noise impacts, costs and reduction techniques.

Ian Bateman, Brett Day, Iain Lake and Andrew Lovett (2001), *Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study*, Scottish Executive Development Department (www.scotland.gov.uk); at www.scotland.gov.uk/library3/housing/ertpv.pdf

Mark Delucchi and Shi-Ling Hsu (1998), "External Damage Cost of Noise Emitted from Motor Vehicles," *Journal of Transportation and Statistics*, Vol. 1, No. 3, (www.bts.gov/publications/jts/) October 1998, pp. 1-24. Also see Mark Delucchi, "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, Vol. 34, No. 2, (www.bath.ac.uk/e-journals/jtep/), May 2000, pp. 135-168.

M.G. Dittrich, H.W. Jansen and A.M. van Noort (2010), *Methods Of Measurement For Peak Noise During Loading And Unloading*, MON-RPT-2010-00466, TNO (www.piek-international.com); at www.piek-international.com/include/downloadFile.asp?id=4.

EC (2005), *ExternE: Externalities of Energy - Methodology 2005 Update*, Directorate-General for Research Sustainable Energy Systems, European Commission (www.externe.info).

EEA (2011) *NoiseWatch*, Eye On The Earth, European Environment Agency (www.eea.europa.eu/data-and-maps)

EU (1995), *Calculation of Road Traffic Noise*, Directorate for Noise and Traffic, European Union (www.ec.europa.eu); at www.xs4all.nl/~rigolett/ENGELS/index.html

U.S. Federal Highway Administration Documents (www.fhwa.dot.gov):

- (1997), *Highway Traffic Noise in the US* (www.nonoise.org/library/highway/probresp.htm)
- (1980), *Highway Traffic Noise* (www.nonoise.org/library/highway/traffic/traffic.htm)
- (1999), *The Environmental Guidebook* (www.fhwa.dot.gov/environment/guidebook/index.htm)
- Highway Traffic Noise (www.fhwa.dot.gov/environment/htnoise.htm)

Caroline Evans, et al. (2015), *Updating Environmental Externalities Unit Values*, Austroads (www.austroads.com.au); at www.onlinepublications.austroads.com.au/items/AP-T285-14.

INFRAS and IWW (2004), *External Costs of Transport – Update Study*, Community of European Railway Companies (www.cer.be) and the International Union of Railways (www.uic.asso.fr).

David Gillen (2007) *Noise and the Full Cost Investigation in Canada: Final Report - Estimation of Noise Costs due to Road, Rail and Air Transportation in Canada*, Transport Canada (www.tc.gc.ca); at www.tc.gc.ca/pol/en/aca/fci/transmodal/menu.htm.

Paul A. Kaseloo and Katherine O. Tyson (2006), *Synthesis of Noise Effects on Wildlife Populations*, Federal Highway Administration (www.fhwa.dot.gov).

M. Maibach, et al. (2008), *Handbook on Estimation of External Cost in the Transport Sector*, CE Delft (www.ce.nl); at http://ec.europa.eu/transport/themes/sustainable/doc/2008_costs_handbook.pdf.

Matthew McCallum-Clark, Rochelle Hardy and Malcolm Hunt (2006), *Transportation and Noise: Land Use Planning Options for a Quieter New Zealand*, Land Transport New Zealand Research Report 299 (www.ltsa.govt.nz); at www.ltsa.govt.nz/research/reports/299.pdf.

The *Noise Pollution Clearinghouse* (www.nonoise.org) is a US based non-profit organization with extensive online noise related resources.

PIEK (www.piek-international.com) is a standard established by Dutch government agencies which limits vehicle noise to 60dB(A) at 7.5 metres from the source.

SUTP (2011), *Noise and Its Abatement*, Module 5c Noise, Sustainable Urban Transport Project (www.sutp.org); at www.sutp.org/index.php?option=com_content&task=view&id=2819.

Swiss ARE (2004), *External Noise Costs of Road and Rail Traffic in Switzerland in 2000* (*Externe Lärmkosten des Strassenund Schienenverkehrs der Schweiz, Aktualisierung für das Jahr 2000*), Swiss Federal Office of Spatial Development (www.are.admin.ch); at www.are.admin.ch/themen/verkehr/00252/00472/03389/index.html?lang=en.

SYLVIE (www.sylvie.at) is developing practical methods to evaluate and alleviate urban noise.

TRB (2005), "Transportation Noise: Measures and Countermeasures," *TR News* (special issue), Transportation Research Board (www.trb.org), Sept./Oct.; at http://trb.org/news/blurb_detail.asp?id=5546.

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Anming Zhang, Anthony E. Boardman, David Gillen and W.G. Waters II (2005), *Towards Estimating the Social and Environmental Costs of Transportation in Canada*, Centre for Transportation Studies, University of British Columbia (www.sauder.ubc.ca/cts), for Transport Canada; at www.sauder.ubc.ca/cts/docs/Full-TC-report-Updated-November05.pdf.

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A comparison of green and conventional diesel bus noise levels

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ABSTRACT
The growing use of green buses has been fueled by the need for reducing noise emissions as well as airborne particulates. Hybrid diesel-electric, electric trolleybus and compressed natural gas (CNG) buses are all promoted to have lower noise levels than conventional diesel buses. This paper provides a general comparison of the noise levels from these vehicle types under idling, acceleration and constant-speed pass by operations.

1. INTRODUCTION
In one project for the Maryland Mass Transit Administration (MTA) in which alternative vehicle types were considered, buses with purely electric propulsion systems were found to have noise impacts extending only about one-third the distance as those for conventional diesel buses.[i] Diesel-electric hybrid buses are widely believed—and promoted—to be significantly quieter than conventional buses: "Utilizing hybrid electric technology, theses buses will dramatically reduce both engine noise and emissions."[ii]

Bus transit is virtually universal in population centers. Bus rapid transit (BRT), which incorporates features of light rail transit systems, is generating widespread interest. Choices are available today that may permit bus operations with significantly less noise impact. Currently, many transit agencies are beginning to use or demonstrate diesel-electric hybrid buses due to the interest in more environmentally friendly bus systems and sustainability.[iii] Available data documenting the potential benefit in reduced sound levels from technologies, especially diesel-electric hybrids, are rather limited. This paper presents a general description of these bus technologies, a comparison of *available* noise emission levels of some of the more common bus technologies being used by North American transit agencies and a comparative overview of the noise emission results.

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2. BUS VEHICLE TECHNOLOGIES

The most common bus vehicle types can be differentiated as:

a. Diesel
b. Compressed natural gas
c. Diesel-electric hybrid
d. Electric trolleybus (with overhead catenary)

Conventional diesel buses are the most prevalent bus technology in use (80% of total North American fleet), followed by compressed natural gas (CNG) and liquefied natural gas (15% of total fleet). As of 2006, only four transit agencies utilize electric trolleybus vehicles comprising only a small percentage of the total fleet.[iv]

Diesel buses with compression ignition engines use diesel fuel for propulsion and electric power for auxiliary equipment. Unlike gasoline engines that require a spark for ignition, diesel engines compress the fuel-air mix and raise its temperature high enough to cause ignition. Noise sources from diesel buses are generally caused by the exhaust system, radiation of the engine block, the cooling system (especially fans), air intake components and tire/pavement-interaction noise.

CNG buses utilize a reciprocating internal-combustion engine similar to conventional diesel buses except that in lieu of diesel fuel they use a methane mixture in a spark-ignition engine for propulsion. CNG buses emit fewer EPA-regulated air emissions than diesel buses. The predominant noise sources are similar to that of diesel buses. Different fuel as well as different operating conditions and efficiencies allow CNG buses to potentially have different noise emissions than diesel buses.

Diesel-electric hybrid buses use an on-board diesel engine to produce electric power that charges batteries. The batteries in turn provide electric power to run the electric propulsion motors. The two main types of diesel-electric hybrid propulsion systems are series and parallel drive trains. Series drive train systems only utilize the electric motors for propulsion and the diesel engine is simply a generator for producing power. Parallel drive trains will engage the diesel engine for propulsion under certain conditions where additional power is needed such as accelerating or climbing hills. Noise sources for diesel-electric hybrid buses include the electric propulsion motors in addition to those of conventional diesel buses. The expected benefits of this technology in regard to noise is the ability for the diesel engine to run at a constant speed and at its highest efficiency since it is only needed to power storage batteries.

Electric trolleybus technology has been in use for many years and is best suited for lower speed (40-mph top speed), urban operations. The vehicles tend to have long service lives, but require an overhead-wire infrastructure similar to light rail systems. Electric trolleybuses use electricity from catenary wire systems to power electric motors and auxiliary equipment. Noise sources from electric trolleybuses include the interaction between the catenary wire and the pantograph or trolley poles, electric motors, auxiliary equipment such as cooling fans and air conditioning and the tire/pavement interaction. Although not part of the trolleybus vehicle, substations required for supplying power to the catenary wire system are another source of noise with these systems.

3. BUS NOISE LEVELS

Data presented were evaluated as part of noise studies for the Maryland MTA, Houston Metro, Los Angeles Metro and Neoplan USA. [v, vi, vii]

To assess bus noise impacts for the Maryland MTA Baltimore Red Line Project—and especially to quantify potential benefits of hybrid buses, sound level data measured at the Altoona Bus Research and Testing Center were analyzed. Performance tests included exterior noise measurements 50 ft from the travel lane centerline in accordance with Society of Automotive Engineers (SAE) test procedure J366b, *Exterior Sound Level for Heavy Trucks and Buses*, in three conditions:

- o Full-throttle acceleration from constant speed ≤35 MPH, just prior to transmission upshift.
- o Full-throttle acceleration from standstill.
- o Stationary, with the engine at low idle, high idle, and wide-open throttle.

Sound level data were available for six conventional (including one CNG-fueled) and five hybrid buses (including one CNG-fueled) of various makes and models, and one gas-turbine-electric hybrid (the 24,500-lb AVS). The test buses ranged 22–60 ft in length and up to 66,000 lb in weight. These data will be presented in this paper as streetside-curbside energy average sound levels.

CNG bus noise emissions of Neoplan USA 40-foot and 60-foot articulated buses were measured. These measurements were conducted in support of efforts by Nelson Muffler to design a retrofit muffler for the Neoplan CNG buses to minimize noise emissions particularly under idling conditions. Measurements were conducted of idling noise and acceleration tests in general accordance with SAE standard J366b for full-throttle acceleration from standstill.

Measurements of Irisbus Civis diesel-electric hybrid buses operating for the Southern Nevada RTC were conducted in conjunction with the Houston Metro North Hardy Corridor and Southeast-Universities Corridor Environmental Impact Statements (see figure 3). These measurements include maximum constant-speed pass-by noise levels at 50 feet. The bus is manufactured by a joint venture of Renault and Fiat's industrial vehicle company, Iveco. The Civis is 61 feet in length with an articulation and three axles. Propulsion is provided by individual electric motors on four of the wheels.

In a study for Los Angeles Metro, maximum constant-speed pass-by noise levels were measured of electric trolleybuses operating in revenue service for Seattle Metro. Seatttle Metro electric trolleybuses include both 40-foot and 60-foot buses.

A. Idling Noise Levels

The Maryland MTA data are summarized in Table 1. The hybrid buses showed benefits in the stationary tests—about 2 dBA quieter in idling measurements and about 7 dBA quieter for the wide-open-throttle condition compared to conventional diesel buses. In this comparison, the hybrid buses are slightly, but not significantly, quieter than the conventional buses in the low-idle and high-idle conditions. However, although based upon limited data, the hybrids are significantly quieter in stationary, wide-open-throttle operation.

Table 1. Conventional v. Hybrid Idling Sound Levels
(averages are rounded to nearest whole decibel, air conditioning off, excluding AVS bus)

		EX. STATIONARY SL (dBA)		
PARAMETER	POWERTRAIN	Low Idle	Hi Idle	WOT
Average*	ALL	65	68	75
	conven.	65	69	77
	hybrid	64	67	70
	CON – HYB	2	2	7
Standard Deviation	ALL	2.5	2.9	3.6
	conven.	3.1	3.1	1.7
	hybrid	1.3	2.6	0.5
Count	ALL	11	8	7
	conven.	6	5	5
	hybrid	5	3	2

Measurements of Neoplan 40-foot and 60-foot articulated buses were conducted including several muffler designs intended to reduce low frequency tones (35 Hz). Streetside-curbside averages of idle noise levels of the 40-foot CNG buses with air-conditioning off were 64 dBA under low-idle conditions and the 60-foot CNG bus were 65 dBA for the best muffler design. These data show that idling noise levels of the CNG buses are very comparable to conventional diesel buses.

Idling noise levels were measured of the electric trolleybuses operated by the Massachusetts Bay Transportation Authority (see figure 4). Idling noise levels of the electric trolleybuses are controlled by the specific auxiliary equipment that is running. With the air-conditioning on, low-idle noise levels were 60 dBA at 50 feet. Although data are limited under idling conditions, electric bus technology clearly has a significant benefit in reduced idling noise levels compared to diesel, CNG or diesel-electric hybrid buses. This factor can be of significant benefit to reducing noise impact for communities—especially since this technology is typically utilized in more urbanized areas where bus idling noise can be a common annoyance and source of complaints.

B. Acceleration Noise Levels

The Maryland MTA data are summarized in Table 2. Maximum pass-by sound levels are plotted versus gross vehicle weight in Figure 1. Hybrid buses were slightly quieter than the conventional buses in the wide-open-throttle acceleration, pass-by tests—but not significantly so. The variation between manufacturers was greater than the differences between bus types, as can be seen in Figure 1. The Gillig buses are significantly quieter (at 95% probability level) than the other manufacturers for acceleration from constant-speed—although narrowly *not* significant for acceleration from standstill. Thus, manufacturer design choices may be more significant than diesel bus powertrain in noise emissions.

Table 2. Conventional v. Hybrid Bus—Pass-By Sound Levels
(averages are rounded to nearest whole decibel, full-throttle acceleration, excluding AVS bus)

PARAMETER	POWERTRAIN	EXT. PASS-BY SL (dBA) Const Spd	Standstill
Average	ALL	76	76
	conven.	76	77
	Hybrid	76	75
	CON – HYB	0	2
Standard Deviation	ALL	2.4	2.7
	conven.	2.6	3.1
	Hybrid	2.4	1.9
Count	ALL	11	11
	conven.	6	6
	Hybrid	5	5

These data suggest that hybrid buses provide no significant benefits under acceleration operations *per industry-standard tests.* While hybrids appear to be somewhat quieter in stationary operations and *may* produce lower noise emissions under acceleration, there is no justification for assuming sound level reductions for hybrid buses under acceleration. On the other hand, since manufacturer design philosophies appears to be a significant factor, aggressive specification of vehicle emissions (for either conventional or hybrid buses) may yield useful benefits.

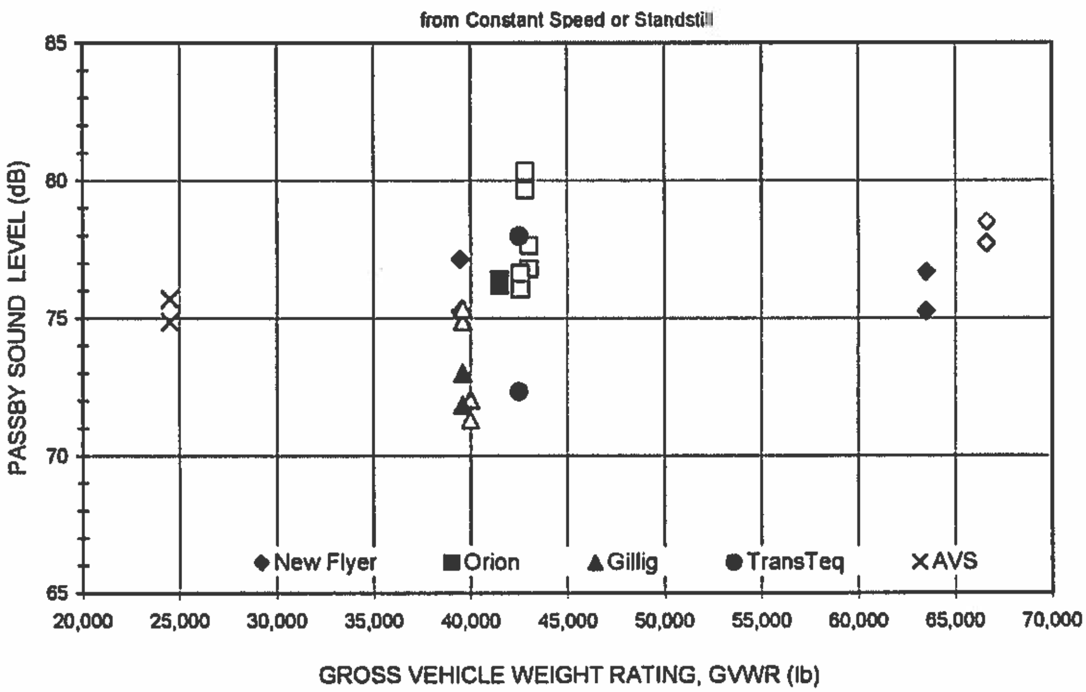

Figure 1. Conventional v. Hybrid Bus—Accelerating Pass-By Sound Levels
HYBRID powertrains = filled symbols, CONVENTIONAL powertrains = open symbols

Accelerating bus noise tests were conducted on a Neoplan 60-foot CNG bus at the Paul Revere Transportation Center in Chelsea, MA. Noise measurements of the bus accelerating from low idle were made at a distance of 50 feet from, and perpendicular to, both sides of the bus. Each test began with the front bumper even with the microphone, and three test runs were conducted for each side. The results of these tests at 50 feet from the bus centerline indicated an average maximum noise level of 80 dBA on the left (street) side of the bus and an average maximum noise level of 78 dBA on the right (curb) side of the bus—with a streetside-curbside average of 79 dBA. These noise levels are approximately 1 to 3 dBA higher than conventional diesel buses.

C. Constant-Speed Pass-By Noise Levels

Maximum noise levels of diesel, hybrid and electric trolleybus pass bys at constant speed are shown in Figure 2. Diesel bus data were measured as part of a study to assess Houston Metro bus fleet baseline noise levels. These data include constant-speed pass bys between 20 and 60 mph and a mixture of transit and suburban buses. These measurements include controlled pass bys from two buses (one MCI and one Neoplan 4700 series) on Beltway 8. Constant-speed pass bys of the Irisbus Civis diesel-electric hybrid were measured between 28 and 42 mph. Electric trolleybus noise levels from constant-speed pass bys were collected between 25 and 35 mph.

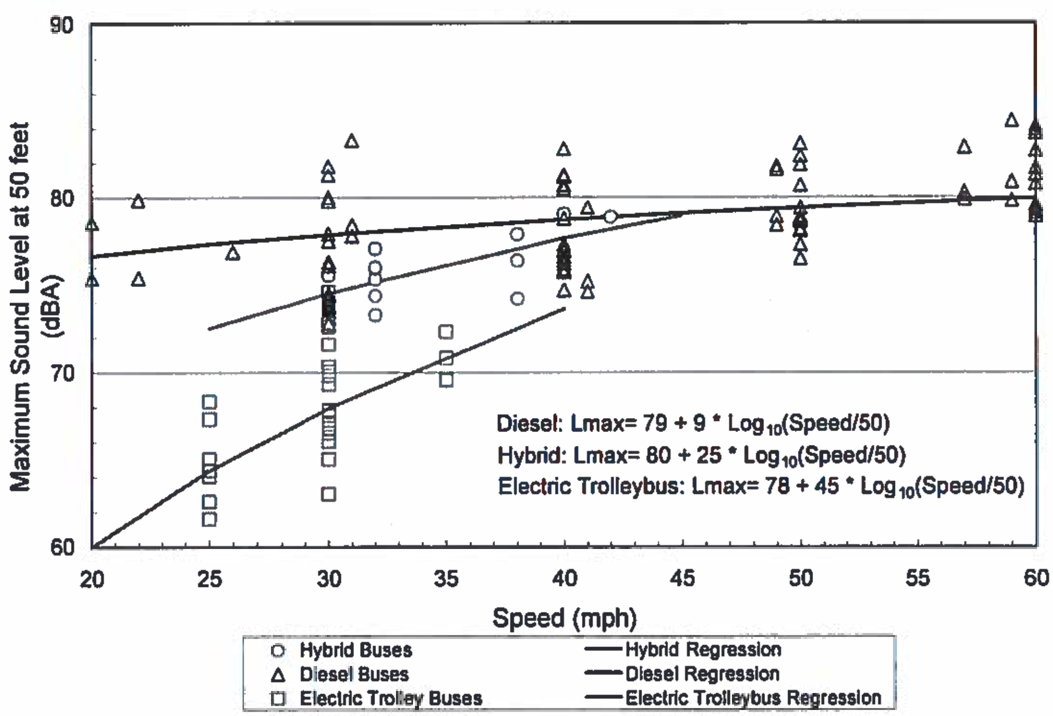

Figure 2. Constant-speed pass-by sound levels for diesel (blue), hybrid (red) and electric trolleybus (green)

This figure shows that at 30 mph hour hybrid buses are approximately 3 dBA lower than conventional diesel buses. At speeds approaching 40 mph, hybrid bus noise levels are within 1 dBA of diesel buses. Electric trolleybuses, in comparison to hybrid buses and conventional buses, are 10 dBA and 7dBA quieter at 30 mph, respectively. At 40 mph, electric trolleybuses are found to be 4 to 5 dBA quieter than hybrid and conventional diesel buses. Although data are not available, as speeds above 40 mph, noise levels of all technology buses are expected to be relatively similar as noise from the tire/pavement-interaction begins to dominate emissions.

3. COMPARATIVE PERFORMANCE OVERVIEW

The bus noise data presented here demonstrate that at under low-idle and high-idle operations there are relatively small differences (0 to 2 dBA) between conventional diesel, CNG and diesel-electric hybrid bus noise emissions. With air-conditioning on, the electric trolleybus was found to have low-idle noise levels of 60 dBA – approximately 5 dBA quieter than other technologies without air-conditioning on. Although measurements of electric trolleybus idle noise levels without air-conditioning were not available, the difference in idling noise levels may be greater than demonstrated here. Under wide-open-throttle operations, stationary noise levels of hybrid buses were shown to be 7 dBA quieter than conventional buses.

Measurements conducted according to SAE J366 show that there is little difference (0 to 2 dBA) between conventional diesel and hybrid buses. CNG buses have not been shown to be quieter than diesel and hybrid buses –in fact, measurements of the 60-foot articulated Neoplan CNG buses are shown to be 2 to 4 dBA louder than conventional and hybrid buses, respectively.

Under low-speed (below 40 mph) constant-speed pass bys, the differences in maximum noise levels among the different bus technologies are greatest. At 30 mph, hybrid buses are 3 dBA quieter than conventional diesel buses and electric trolleybuses are 10 dBA quieter than diesel buses. At speeds 40 mph and above, maximum noise levels for all bus technologies begin to converge as noise from the tire/pavement-interaction begins to dominate.

These data show that the electric trolleybuses have significantly lower noise levels than other technologies. While battery-electric buses are not very common, the same benefits of noise as well as the elimination of catenary/pantograph noise should be expected. While diesel-electric hybrid buses have been found to produce slightly lower noise emissions than conventional diesel buses, particularly under low-speed pass bys, the potential noise benefits of this technology do not seem to have been realized, yet. Differences in noise levels among bus manufacturers seem to be a significant factor—indicating that improvements to hybrid bus designs could prove to be effective in lowering noise levels from hybrid buses. Such design concepts may include better sound isolation of the diesel engine (since it does not require connection to the drive shaft with a series drive train design) or control systems to regulate the operation of the diesel engine in respect of noise.

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[ii] 2006 GM Corp. advertisement appearing in Washington Post announcing the delivery of 50 GM-powered hybrid buses to the Washington Metropolitan Area Transit Authority.

[iii] Source: American Public Transportation Association Survey, New Bus and Trolleybus Market by Power Source, 2005-2010.

[iv] Source: American Public Transportation Association Survey, Bus and Trolleybus Power Sources, 2006.

[v] Barrett, D.E., et al, "Metropolitan Transit Authority of Harris County Bus Noise Baseline Study", prepared for Metropolitan Authority of Harris County, August, 2004.

[vi] Saurenman, H.J, "Electric Trolley Bus Noise Impact Assessment", prepared for Los Angeles Metro, October, 1992.

[vii] Towers, D.A., et al, "Low-Frequency Noise Effects in Residential Buildings Along a Bus Rapid Transit (BRT) Route", Institute of Noise Control Conference, 2004.

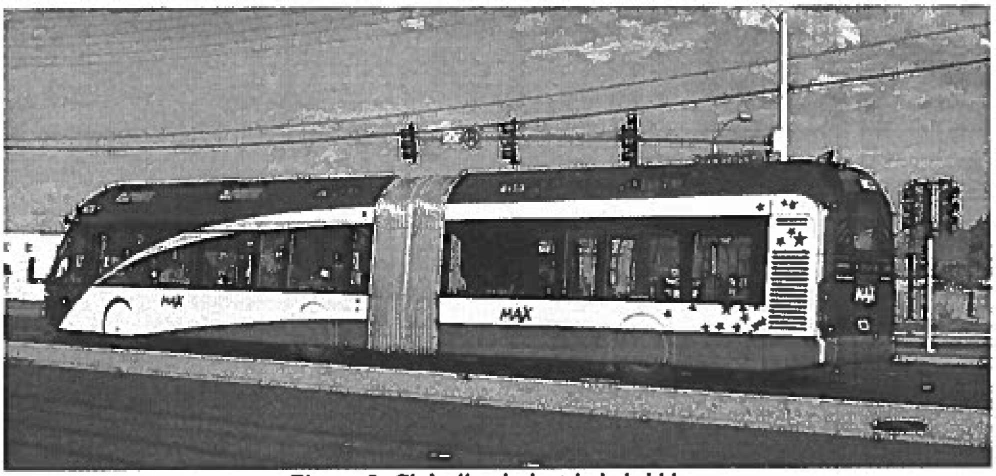

Figure 3. Civis diesel-electric hybrid bus

Figure 4. MBTA electric trolley bus (Arnold Reinhold)